

EVIDENCE FOR ABIOTIC AND BIOTIC INFLUENCES ON GROWTH RATES
AND MIGRATION AND SPATIAL DISTRIBUTION OF YOUNG-OF-THE-YEAR
YELLOW PERCH IN THE INDIANA WATERS OF LAKE MICHIGAN

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
MASTER OF SCIENCE

BY

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BALL STATE UNIVERSITY

MUNCIE, INDIANA

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ABSTRACT

THESIS: Evidence for abiotic and biotic influences on growth rates and migration and spatial distribution of YOY yellow perch in the Indiana waters of Lake Michigan

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We developed a mixed model to determine whether biotic (alewife, spottail shiner, round goby, yellow perch \geq age 1 and yellow perch $<$ age 1 abundances) or abiotic (water temperature, water clarity) factors influenced growth rates in the Indiana waters of Lake Michigan during August from 1984 to 2007. This study suggests that young-of-the-year (YOY) yellow perch growth rates in southern Lake Michigan are influenced by temperature, spottail shiner abundance, and round goby abundance. We also collected age-0 yellow perch to identify details of early life history including timing of migration to pelagic waters, timing of return to nearshore waters, and spatial distribution following return to nearshore waters. This study suggests that yellow perch larvae hatch and are in the nearshore waters from June 1 to June 24, return date for demersal YOY yellow perch ranges from July 8 to August 16, with a mean return date of July 25, and spatial distribution of demersal age-0 yellow perch is relatively homogenous in Indiana nearshore waters.

INTRODUCTION

Yellow perch, *Perca flavescens*, has been extensively harvested commercially, is a highly sought after sport fish, and is an integral member of the nearshore Lake Michigan fish community (Marsden and Robillard 2004). Annual commercial harvest was greater than 550 metric tons from 1985 - 1994 (Brofca and Marsden 1993), and yellow perch has historically comprised as much as 85% of the annual sport catch (Great Lakes Fishery Commission 1995). Yellow perch abundance in Lake Michigan peaked in the mid- 1980's, declined in the early 1990's, and has remained at a reduced level since (Clapp and Dettmers 2004; Marsden and Robillard 2004; Makauskas and Clapp 2008). This low population abundance required fisheries managers to tighten recreational bag limits, and by 1997, close all commercial fisheries except in Green Bay to preserve the fishery (Clapp and Dettmers 2004; Marsden and Robillard 2004). A collaborative lake-wide effort is identifying factors causing yellow perch recruitment failure (Clapp and Dettmers 2004), with a specific focus on early life history (Robillard and Marsden 2001).

Size of young-of-the-year (YOY) fish during the first winter is negatively related with first year mortality and thus, influences recruitment (Irwin et al. 2009). Further, survival of YOY generally has been shown to be greater for fast growing fishes, as vulnerability decreases with size (Houde 1994). Thus, the significance of understanding the factors influencing YOY growth rates may aid scientists in managing the fishery and ultimately dictating the allowable level of exploitation in Lake Michigan, whether it is commercial or recreational.

Since year class strength may be determined by early life history stages (Clady 1976; Anderson et al. 1998), identifying the details of yellow perch spawning, hatch,

pelagic drift, return to littoral waters and the related ontogenetic diet shifts is of paramount importance for sound management. By characterizing the early life history of yellow perch in the Indiana portion, we may more fully identify spawning activity, recruitment limitations, dispersal patterns, and habitat use in the entire southern Lake Michigan basin, facilitating yellow perch management (Urho 1996; Dettmers et al. 2005).

The purpose of this study was two-fold. Our first objective was to determine whether biotic or abiotic factors influence YOY yellow perch growth in southern Lake Michigan. We predict negative effects on growth to include abundances of yellow perch < age 1, alewife, spottail shiner, round goby, yellow perch \geq age 1, and water clarity (Secchi disc depth). We also predict that temperature would have a positive effect on growth of YOY yellow perch. Our second set of objectives included to 1) determine time of larval transition from nearshore hatch sites to pelagic waters, 2) determine time of return of free-swimming, demersal YOY back to nearshore waters, 3) determine whether demersal YOY abundance in catch-per-unit-effort (CPUE) differs spatially in the Indiana waters, and 4) determine whether YOY size measured as total length (mm) differed by sampling unit and zone in the Indiana waters of southern Lake Michigan.

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CHAPTER 1: Changes in size of late summer young-of-the-year yellow perch in the
Indiana waters of Lake Michigan 1984 - 2007: Evidence for abiotic and
biotic influences on growth rates

Abstract – Young-of-the-year (YOY) yellow perch collected from Lake Michigan were examined to determine whether biotic (alewife, spottail shiner, round goby, yellow perch \geq age 1 and yellow perch $<$ age 1 abundances) or abiotic (water temperature, water clarity) factors influenced growth rates. Data used in the analysis were taken from annual bottom trawl catch from three locations in the Indiana waters of Lake Michigan during 1984 - 2007. The most parsimonious model explaining YOY yellow perch growth rates, according to AIC analysis, was a function of temperature, spottail shiner abundance (both positive associations), and round goby abundance (negative association), and explained 46% of the variance. Identifying growth rates for YOY yellow perch provides a better understanding of their early life history and provides some indication of the mechanisms controlling year class strength and ultimately, recruitment.

INTRODUCTION

Yellow perch, *Perca flavescens*, has been extensively harvested commercially, is a highly sought after sport fish and an integral member of the nearshore Lake Michigan fish community (Marsden and Robillard 2004). Annual commercial harvest was greater than 550 metric tons from 1985 - 1994 (Brofca and Marsden 1993), and yellow perch has historically comprised as much as 85% of the annual sport catch (Great Lakes Fishery Commission 1995). Yellow perch abundance in Lake Michigan peaked in the mid-1980's, declined in the early 1990's, and has remained at a reduced level since (Clapp and Dettmers 2004; Marsden and Robillard 2004; Makauskas and Clapp 2008). This low population abundance required fisheries managers to tighten recreational bag limits, and by 1997, close all commercial fisheries except in Green Bay to preserve the fishery (Clapp and Dettmers 2004; Marsden and Robillard 2004). There has been a collaborative effort lake-wide to identify factors causing yellow perch recruitment failure (Clapp and Dettmers 2004), with a specific focus on early life history (Robillard and Marsden 2001). Size of young-of-the-year (YOY) fish is negatively related with overwinter mortality and thus, influences recruitment (Irwin et al. 2009). Further, survival of YOY fish generally has been shown to be greater for fast growing fishes, as vulnerability decreases with size (Houde 1994). Thus, understanding the factors influencing YOY growth rates may aid scientists in managing the fishery and ultimately dictating the allowable level of exploitation in Lake Michigan, whether it is commercial or recreational.

Many factors (biotic and abiotic) influence YOY fish growth, including temperature (Ney and Smith 1975; Power and Van Den Heuvel 1999), water clarity (Neuman et al. 1996; Mayer et al. 2000), food availability (Noble 1975; Mills and Forney

1981; Boisclair and Leggett 1989), and population density (Post and McQueen 1994; Purchase et al. 2005). Warmer water temperatures promote yellow perch growth (Ney and Smith 1975) up to the optimum of 22°C (Brown et al. 2002). In a study of 21 northern lakes, Power and Van Den Heuvel (1999) found that growth rates of YOY yellow perch were positively associated with the number of days above 13.5 °C during the growing season. Temperature may influence growth rates through behavior changes, as yellow perch in Lake Michigan sought out the warmer waters during the summer (Rydell et al. 2010), presumably to feed. Water clarity may also influence growth as yellow perch are sight feeders (Jansen and Mackay 1992). Secchi disc depth may have a positive relationship with YOY yellow perch growth as increased water clarity increases foraging efficiency and results in higher growth rates (Hinshaw 1985; Mayer et al. 2001). However, the possibility of water clarity to have a negative relationship with YOY yellow perch growth must not be ignored. Because larval yellow perch begin to feed on zooplankton even before they have exhausted their yolk sac (Urho 1996), not only is the quantity of food critical to larval yellow perch growth, but also the timing of when different species and sizes of zooplankton are available to yellow perch (Noble 1975; Mills and Forney 1981; Boisclair and Leggett 1989; Cushing and Horwood 1994; Dettmers et al. 2003; Graeb et al. 2004).

Food availability for predators depends on production levels of prey and the population densities of all community organisms that may be interacting. For example, YOY yellow perch growth rates can be density dependent (Post and McQueen 1994; Irwin et al. 2009). Further, growth rates of YOY yellow perch may be related to population densities of other fishes in the community, including alewife *Alosa*

pseudoharengus, spottail shiner *Notropis hudsonius*, and round goby *Neogobius melanostomus*, through predation and competition (Brandt et al. 1987; Shroyer and McComish 2000; Robillard and Marsden 2001; Purchase et al. 2005).

Our objective for this study was to determine whether biotic or abiotic factors influence YOY yellow perch growth in southern Lake Michigan. We predicted negative effects on growth to include abundances of yellow perch < age 1, alewife, spottail shiner, round goby, yellow perch \geq age 1, and water clarity (Secchi disc depth). We also predicted that temperature would have a positive effect on growth of YOY yellow perch.

METHODS

Study location and fish sampling

Sampling was conducted at three sites in the Indiana waters of southern Lake Michigan (Figure 1). Sites M and K are located two kilometers east and west of Michigan City Harbor, respectively, and were sampled from 1984 - 2007, while site G is located six kilometers northwest of Burns Harbor, and was sampled from 1989 - 2007 (Figure 1). Substrate at the three sites is predominantly sand, with additionally some undulating clay ridges at site K (Shroyer and McComish 1998; Lauer et al. 2004).

Fishes were sampled with a semi-balloon otter trawl at night bi-monthly from June through August. A sample consisted of six 10 minute tows along a one kilometer transect for a total trawling effort of one hour. The trawl had a 4.9 m head rope, 5.8 m footrope, 38 mm stretched mesh nylon body, and 32 mm stretched mesh cod end with a 13 mm nylon liner and was fished along the 5 m depth contour at an average tow speed of 5.5 - 6.0 km/h. Fishes were stored on ice and processed dockside (identified and

enumerated) within 12 hours of capture. When yellow perch YOY sample abundance exceeded 300, measurement of total length to the nearest mm was limited to 300 randomly selected yellow perch.

Model development and validation

Only YOY yellow perch captured in both sample periods during August were used to calculate growth rates. Fish collections taken earlier in the summer either had no or few YOY yellow perch, precluding meaningful statistical analysis. Late summer daily growth for any given year was based on population length-frequency analysis (DeVries and Frie 1996) calculated by subtracting the mean total length (mm) of the early August sample from the mean total length of the late August sample and dividing by the number of intervening days.

Abiotic measurements came from two sources. Daily water temperature (May - October) was obtained from Saint Joseph Water Filtration Plant, Saint Joseph, Michigan. Secchi disc depth was taken before each trawl sample and annual means were used to estimate Secchi disc depth for each site.

A mixed model, which is a generalization of the general linear model, was used to assess the influence of abiotic and biotic factors on YOY yellow perch growth (Patrick Forsythe, personal communication, 2010). Site and year were treated as random effects, while possible fixed effects (model covariates) included temperature (T), Secchi disc depth (SD), yellow perch < age-1 CPUE (YOY), yellow perch \geq age-1 CPUE (YEP), alewife CPUE (ALE), spottail shiner CPUE (SPS), and round goby CPUE (ROG). All covariates with the exception of Secchi disc depth were \log_{10} transformed due to variations from normality (Shapiro-Wilk test $P < 0.05$). All possible fixed effects were

run in single parameter models and ranked by Akaike Information Criterion (AIC) (Table 1). Fixed effects exhibiting a significant relationship ($\alpha = 0.05$) were retained for testing in multiple parameter models. When constructing the multiple parameter models, fixed effects were added, beginning with those that had the lowest AIC values when run as single parameter models, until multiple parameter model AIC ceased to improve. All possible interactions of the included fixed effects were then tested and included if they improved model fit (using AIC) while retaining significance. Multiple parameter models were compared by AIC to select the best fitting model (Table 2). Likelihood-ratio tests were used to ensure that improvements to model AIC from inclusion of additional fixed effects were statistically significant and the most parsimonious model was selected. The most parsimonious model was validated by 1) plotting the residuals, and 2) plotting the predicted growth estimates against observed growth values. All statistical analyses were conducted with SAS software 9.1.3 (SAS 2003).

RESULTS

Growth rates of yellow perch and CPUE of nearshore fish species varied annually over the 23 year study period. Estimates of YOY yellow perch growth during August ranged from 0.01 mm/day in 2002 to 1.41 mm/day in 1995, with a mean (SE) of 0.55 (0.04) for the entire study period (Figure 2). Mean annual CPUE for yellow perch < age-1 ranged from < 1 in 1988 to 55 in 1989 (Figure 3) while older yellow perch (\geq age-1) mean CPUE (SE) ranged from 9 (4) in 1995 to 2575 (186) in 1986 (Figure 3). Spottail shiner mean CPUE peaked at 2283 in 1995, while alewife mean CPUE was highest in

2003 (Figure 4). Round goby were not present in trawl samples until 1998, but from 1998 - 2007 round goby mean CPUE ranged from < 1 in 1998 to 385 in 2005 (Figure 4).

Abiotic conditions also varied during 1984 - 2007 in southern Lake Michigan. Mean water temperature (May – October) ranged from 14.7 °C in 1984 to 17.6 °C in 1987 and demonstrated a trend toward cooler temperatures in recent years (Figure 5). Mean (SE) Secchi disc depth ranged from 2.1 (0.3) m at site K in 1993 to 5.0 (0.0) m at site G in 1997 (Figure 5).

Single parameter models (Table 1) resulted in temperature, spottail shiner abundance, and Secchi disc depth demonstrating positive relationships with YOY yellow perch growth while round goby, yellow perch \geq age-1, alewife, and yellow perch $<$ age-1 abundances demonstrated negative relationships. Two parameters, Secchi disc depth and YOY yellow perch abundance, were not significant and were not included in the multiple parameter model analyses.

All possible combinations of multiple parameter models were built using both significant single model parameters and interactions. No interactions were significant and thus were excluded. The most parsimonious model (Table 2) included the single parameters of temperature, spottail shiner, and round goby. Temperature had a strong positive influence on growth ($\beta = 1.26$) and explained the largest amount of variation in our model (Figure 6, Table 1). In spite of this result, temperature in the three parameter model was not significant. Spottail shiner CPUE explained the second largest amount of variation in the model with a positive relationship ($P = 0.001$, $\beta = 0.29$) (Figure 7, Table 1), while round goby CPUE had a negative relationship with yellow perch YOY growth ($P = 0.001$, $\beta = -0.13$) (Figure 8). Strong support for a second model using temperature,

spottail shiner, round goby, as well as, alewife could be made, as the Δ AIC between these two models was < 2.0 ($3.1 - 1.5 = 1.6$) and suggests these two models are indistinguishable (Burnham and Anderson 2002). The remaining models (Table 2) provided the next best fit, while all other models tested had greater AIC values and are not shown.

Validation of the most parsimonious models was supported by two techniques. Model residuals and fixed effects of temperature (Figure 9), spottail shiner (Figure 10), and round goby (Figure 11) were randomly distributed in plots, an indication that the model fits the data well (Pope and Kruse 2007). Our regression analysis demonstrated the growth model explained almost half the variation in observed growth (Figure 2).

DISCUSSION

Our models demonstrated that both abiotic and biotic effects influenced YOY yellow perch growth rates in southern Lake Michigan, explaining nearly half of the observed variation (Figure 2). Accounting for this much variation is difficult, considering the plethora of environmental impacts influencing growth (Purchase et al. 2005) that were outside the scope of this study. The identification of temperature as a factor controlling growth rates was expected (Ney and Smith 1975; Power and Van Den Heuvel 1999; Brown et al. 2002), although in the development of the full model, the influence of temperature on growth was less defined. The negative connection of round goby abundance to yellow perch growth may simply be competitive interspecific interactions for food (Jude et al. 1995; Kuhns and Berg 1999; Tyson and Knight 2001; Compton and Kerfoot 2004), while the significance of spottail shiner and their positive influence on

growth rates has never been identified. The influence of alewife on YOY yellow perch was not apparent, but a negative influence of alewife was found on yellow perch recruitment in this area of the lake (Shroyer and McComish 2000). It is important to note that our model and the model by Shroyer and McComish (2000) are not autonomous; some of the same data (abundance of yellow perch \geq age-1 and alewife for years 1984 - 1997) were used in both analyses. Finally, other abiotic (light) and biotic (zebra mussels, zooplankton) factors affect yellow perch growth (Huh et al. 1976; Mayer et al. 2000; Dettmers et al. 2003), but were not examined by our model and could be accounting for some of the unexplained variability observed.

Our results are consistent with the understanding that warmer water temperatures result in increased YOY yellow perch growth (Ney and Smith 1975; Clady 1976), (Figure 5). In our model, we found temperature to be the strongest single explanatory variable, similar to Power and Van Den Heuvel (1999). We suspect that water temperature results might have been further clarified if water temperature was quantified differently. Mean water temperatures from a single station allowed some measure of comparison over the study period, but did not depict the range of water temperatures used by the fish. Adult yellow perch are behaviorally adept at seeking out preferable water temperature (Rydell et al. 2010) and Lake Michigan exhibits a thermal stratification regime that is dynamic and changes with seasons, weather patterns (e.g., wind strength and direction) and tributary inputs (Mortimer 2004). Unfortunately, how temperature influences YOY behavior and movement in Lake Michigan is unknown. Should future studies develop a more appropriate way of measuring specific temperature use by YOY fish, our model might explain more variation, or provide a better fit.

The negative relationship between YOY yellow perch growth and round goby abundance could be explained through either exploitation or interference competition (Janssen and Jude 2001). Although the round goby has only been a member of the Lake Michigan nearshore fish community since 1997 (Clapp et al. 2001) it has aggressively established itself at the expense of two native benthic fishes, mottled sculpin, *Cottus bairdii*, and johnny darter, *Ethostoma nigrum* (Janssen and Jude 2001; Lauer et al. 2004). Round goby suppress mottled sculpin recruitment through interference competition, driving guard males off nest sites and consuming eggs (Jude et al. 1995; Janssen and Jude 2001). Round gobies also exhibit exploitation competition, out-competing other members of the benthic fish community for limited food and habitat space (Jude et al. 1995; Janssen and Jude 2001; Lauer et al. 2004). Like YOY yellow perch, round gobies consume benthic prey items. Diet overlap between round gobies and small yellow perch was found in Lake Erie (Marschner, 2003), and we expect a similar overlap exists in Lake Michigan.

Round gobies can feed in low light conditions with their sensitive lateral line (Dubs and Corkum 1996), a competitive advantage over YOY yellow perch that feed by site (Jansen and Mackay 1992). The addition of the round goby to the nearshore benthic community has led lake managers to hypothesize that the round goby may negatively influence yellow perch recruitment (Jude et al. 1995; Janssen and Jude 2001; Truemper et al. 2006). Round gobies are highly abundant on the rocky habitat in the nearshore waters of southern Lake Michigan (Janssen and June 2001; personal observation 2009), a habitat type which they vigorously defend (Jude et al. 1995). These rocky habitats are also the preferred spawning substrate for yellow perch (Robillard and Marsden 2001). This

physical niche overlap between these two species (Jude et al. 1995; Kuhns and Berg 1999; Tyson and Knight 2001; Compton and Kerfoot 2004) may be a causal mechanism contributing to the low recruitment of yellow perch since the late 1990's.

Our model demonstrated a positive relationship between YOY yellow perch growth and spottail shiner abundance (Figure 7). This relationship with growth was inconsistent with our original hypothesis that spottail shiner abundance would negatively influence YOY yellow perch growth. Although no previous relationship between spottail shiner abundance and YOY yellow perch growth has been described, a limited data analysis suggests a negative association exists between spottail shiner abundance and recruitment of yellow perch to adults (Patrick Forsythe, personal communication, 2010). Lastly, ontogenetic diet shifts associated with the early life history stages of yellow perch make determining interactions with other fish species and prey items difficult. These interspecific relationships may change depending on the size and maturity of fishes examined (Graeb et al. 2006),

Spottail shiner and larval yellow perch are both schooling species that feed on zooplankton (Seghers 1981). The positive relationship observed in our model could be due to a mutual dependence on zooplankton as food but different realized niches. A feeding study conducted by Bulkley et al. (1976) found *Bosmina* to be the single most abundant zooplankton in spottail shiner stomachs. In contrast, yellow perch preferred copepod nauplii when given a choice and when this invertebrate was common in the plankton (Bulkley 1976; Graeb et al. 2004). While diet overlap exists at some stages (Hartman et al. 1992; Pothoven et al. 2000), the results from our modeling indicate that competition from spottail shiners was not limiting yellow perch growth at the YOY stage.

Our alternative (second) model demonstrated that alewife had a negative influence on YOY yellow perch growth rates (Table 2). Alewives prey upon larval yellow perch and compete for food resources with post larval yellow perch these interactions may influence greater energy expenditures and reduced foraging ability by yellow perch because of predation risk (Brandt et al. 1987; Seghers 1981; Pothoven and Vanderploeg 2004). These findings define a possible mechanism linking the negative impact alewives have on YOY yellow perch and ultimately recruitment (Shroyer and McComish 2000).

Considering the known influence of size on first year overwintering survival of yellow perch (Anderson 1988; Miller et al. 1988; Eckmann 2004), we suspect that factors promoting the growth of YOY yellow perch will ultimately influence recruitment in southern Lake Michigan. Although managers cannot alter temperature regimes, it may be possible to reduce alewife abundance through changes in harvest regulations or salmonine stockings that would influence predator - prey dynamics. If alewife abundance was reduced, growth rates of yellow perch, as defined by our model, would increase, promoting greater first year survival. In turn, reaching age-1 appears to be a milestone, as recruitment from this age to fish that reach quality size (200 mm) is predictable (Shroyer and McComish 1998). The influence of round gobies on benthic fishes has been identified (Janssen and Jude 2001; Lauer et al. 2004), but their specific impact on spawning, larval, or demersal yellow perch is not well defined. Further, little is known regarding the biotic relationship between spottail shiner and yellow perch, suggesting a void exists in determining the causal mechanisms influencing the early life history fate of yellow perch and the numerically dominant fishes in the nearshore community.

Management strategies for the yellow perch in southern Lake Michigan, therefore, may lie more in the understanding of the environment, including other members of the fish community, rather than implementation of direct influences on the yellow perch population.

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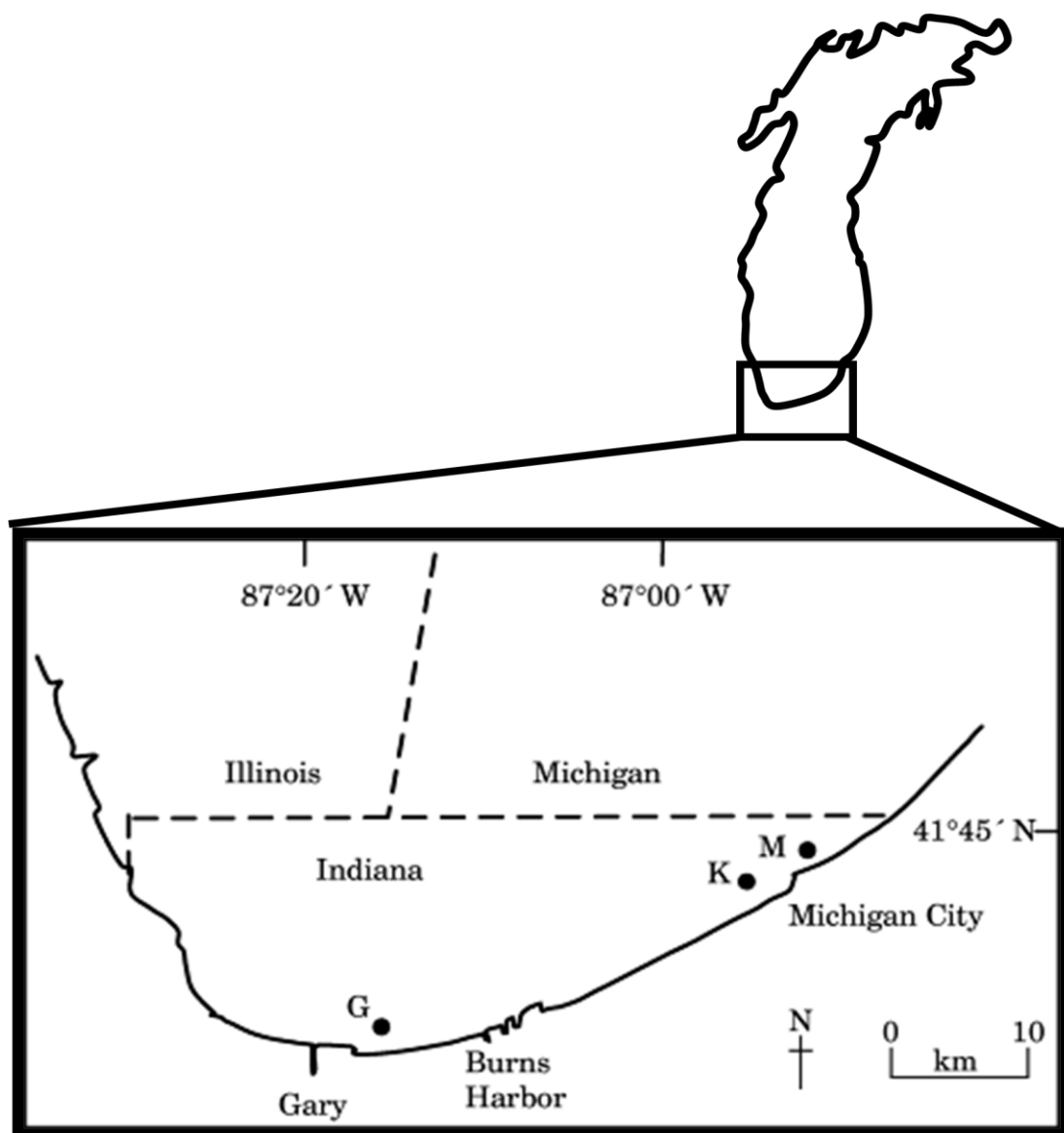


Figure 1. Map of three sample sites (M, K, and G) in the Indiana waters of southern Lake Michigan.

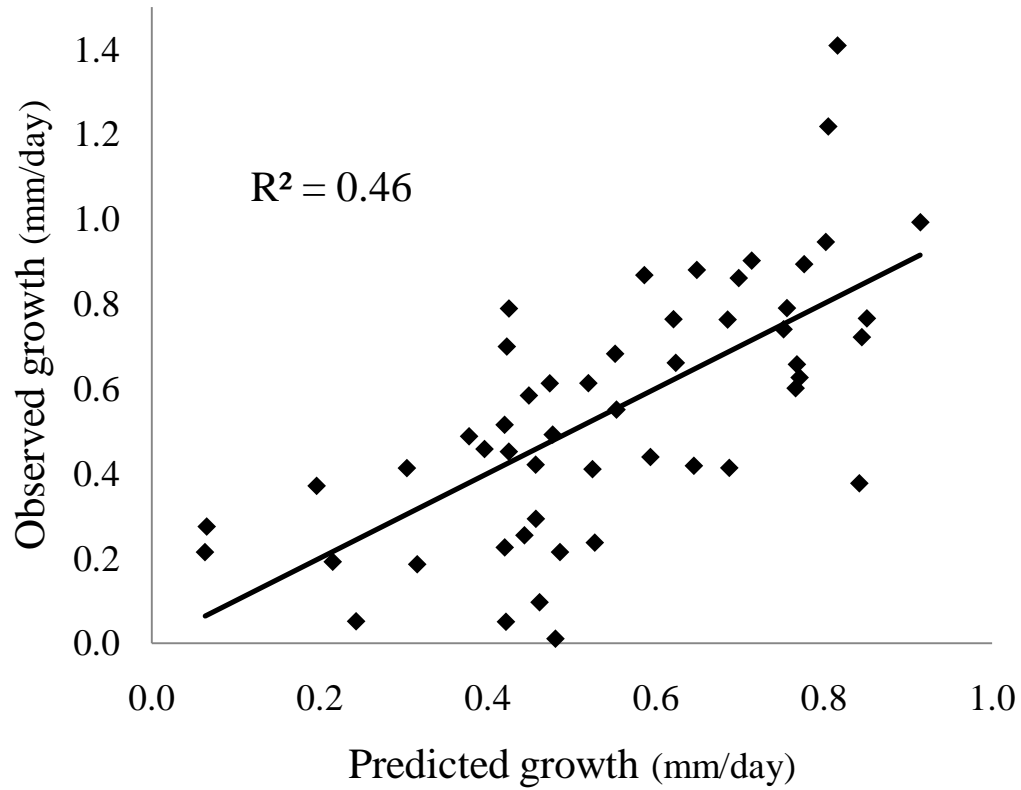


Figure 2. Observed growth rate (mm/day) of yellow perch age < 1 (Y-axis) plotted against model predicted growth rate (mm/day) of yellow perch age < 1 (X-axis) from sites M, K, and G in Indiana waters of Lake Michigan from 1984 - 2007. The 1984 - 1988 data represent sites M and K; the 1989 - 2007 data represent sites M, K, and G.

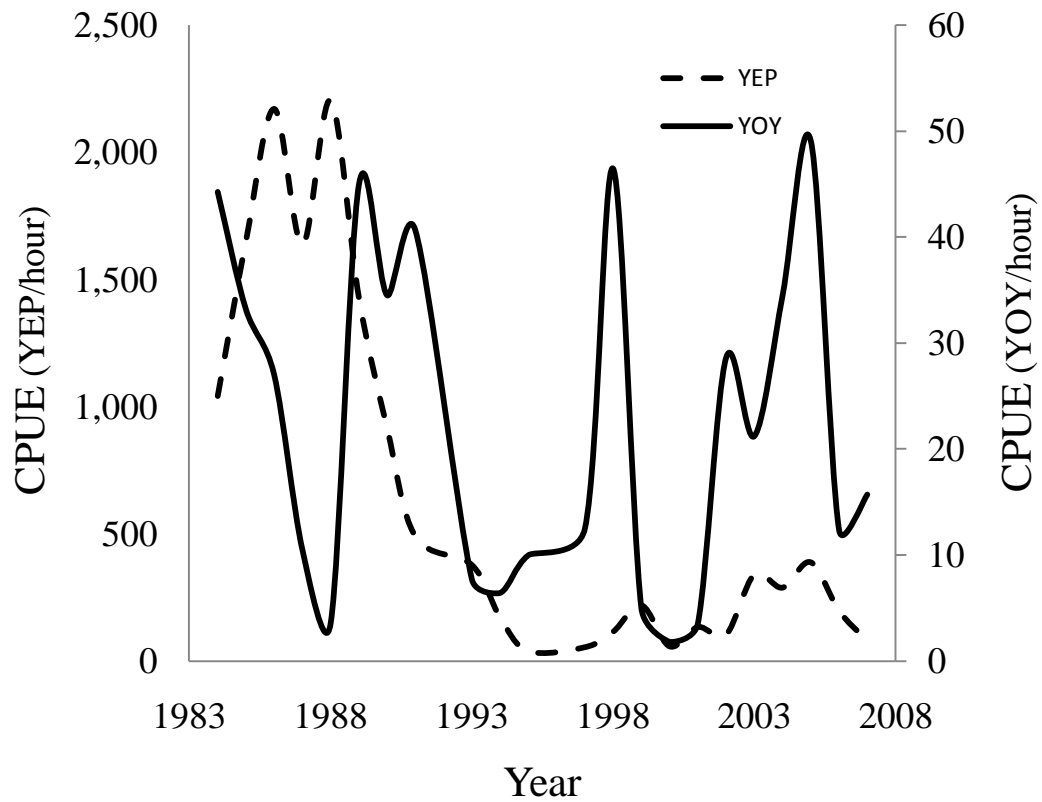


Figure 3. Annual trawl CPUE of yellow perch age < 1 (YOY) and yellow perch age ≥ 1 (YEP) from pooled sites M, K, G in Indiana waters of Lake Michigan from 1984 - 2007. The 1984 - 1988 data represent pooled sites M and K; the 1989 - 2007 data represent pooled sites M, K, and G.

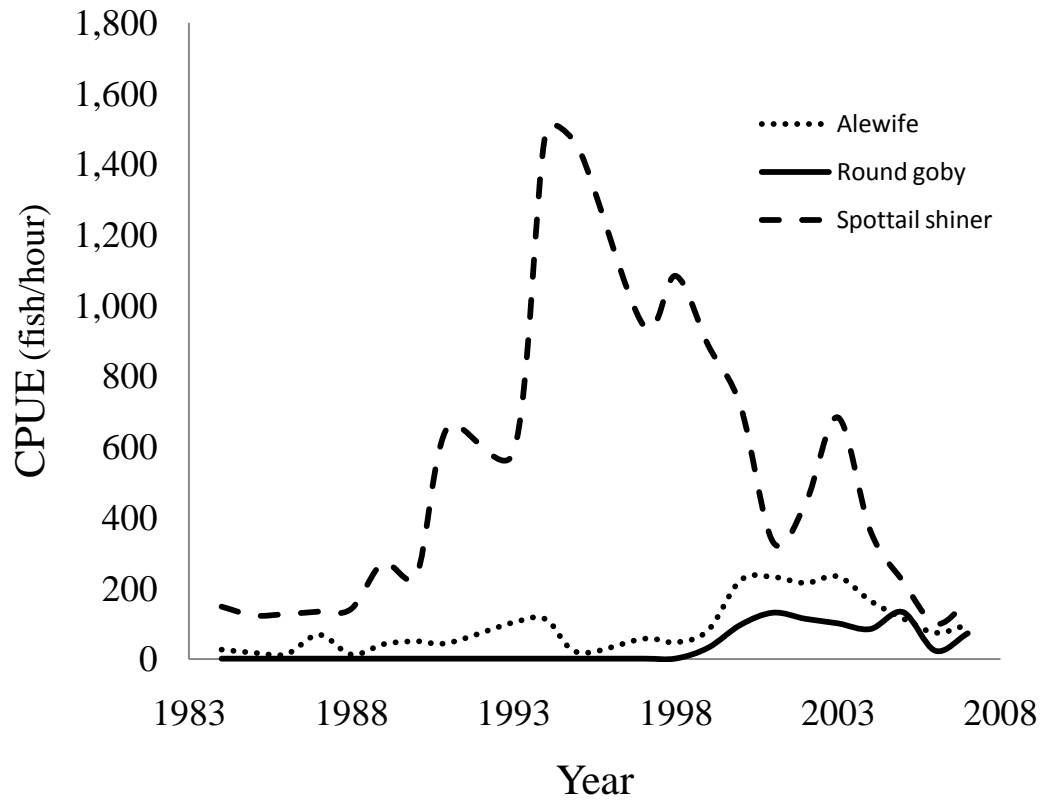


Figure 4. Annual trawl CPUE of alewife (ALE), spottail shiners (SPS) and round gobies (ROG) from pooled sites M, K, G in Indiana waters of Lake Michigan from 1984 - 2007. The 1984 - 1988 data represent pooled sites M and K; the 1989 - 2007 data represent pooled sites M, K, and G.

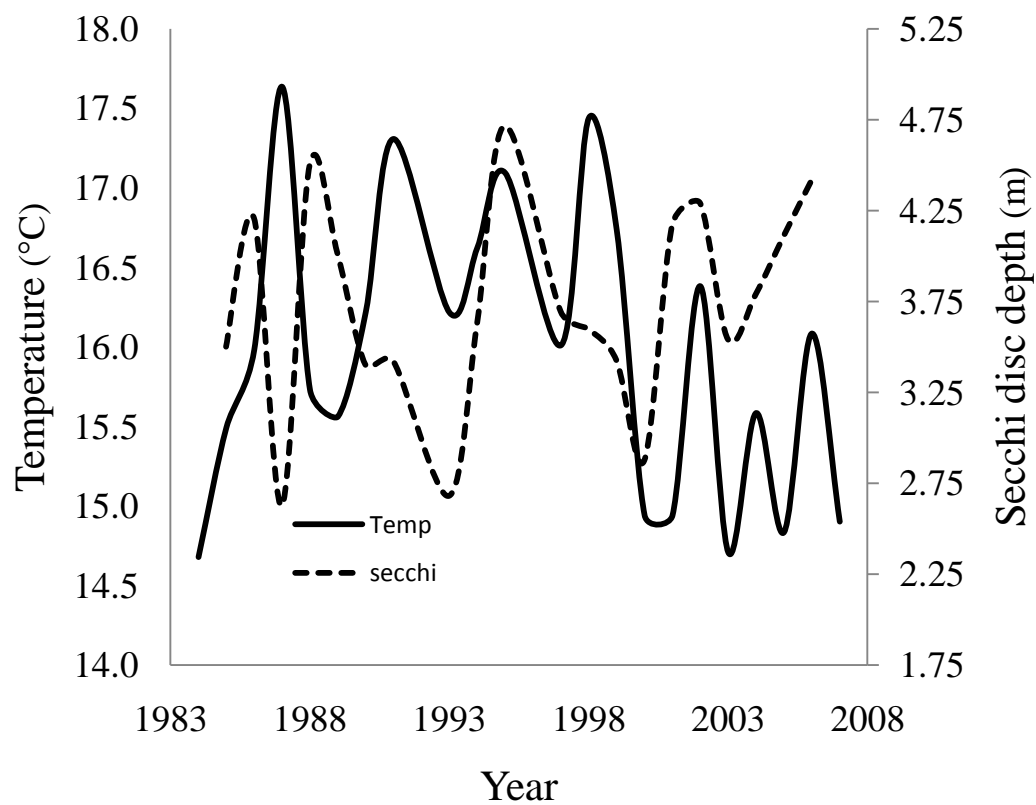


Figure 5. Annual water temperature and Secchi disc depth from the pooled sites M, K, G in Indiana waters of Lake Michigan from 1984 - 2007. The 1984 - 1988 data represent pooled sites M and K; the 1989 - 2007 data represent pooled sites M, K, and G.

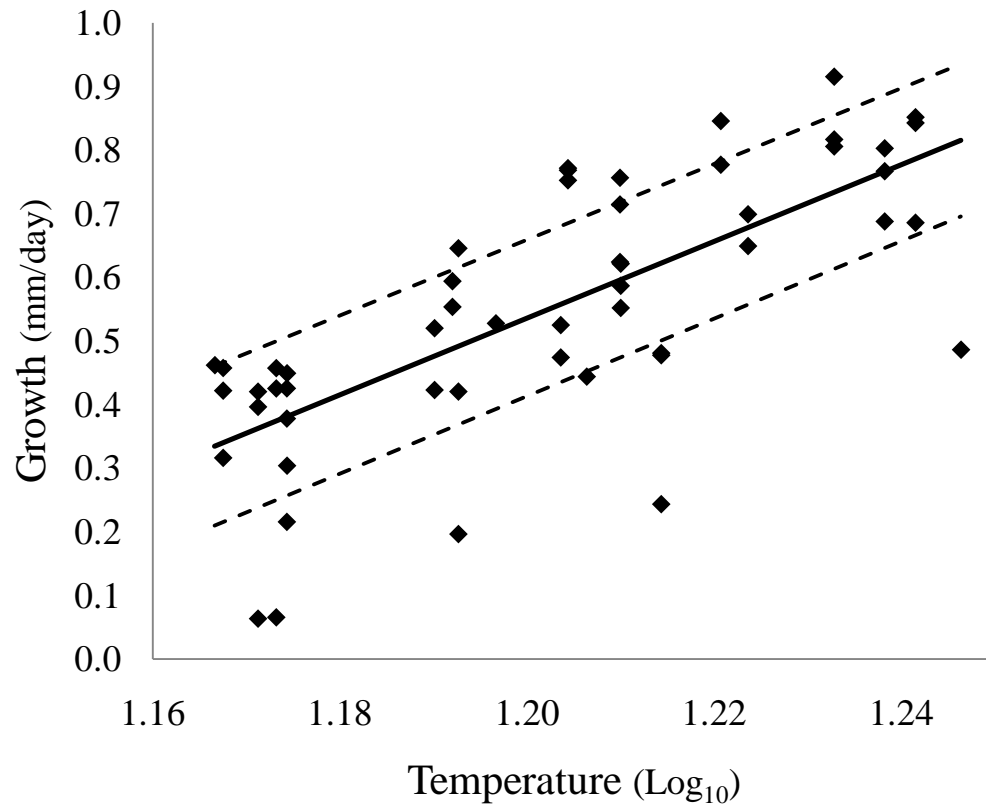


Figure 6. Model predictions of growth (mm/day) of yellow perch age < 1 (Y-axis) as a function of temperature (Log_{10}) May-Oct. (X-axis), with best fit line and 95% confidence intervals (dashed lines).

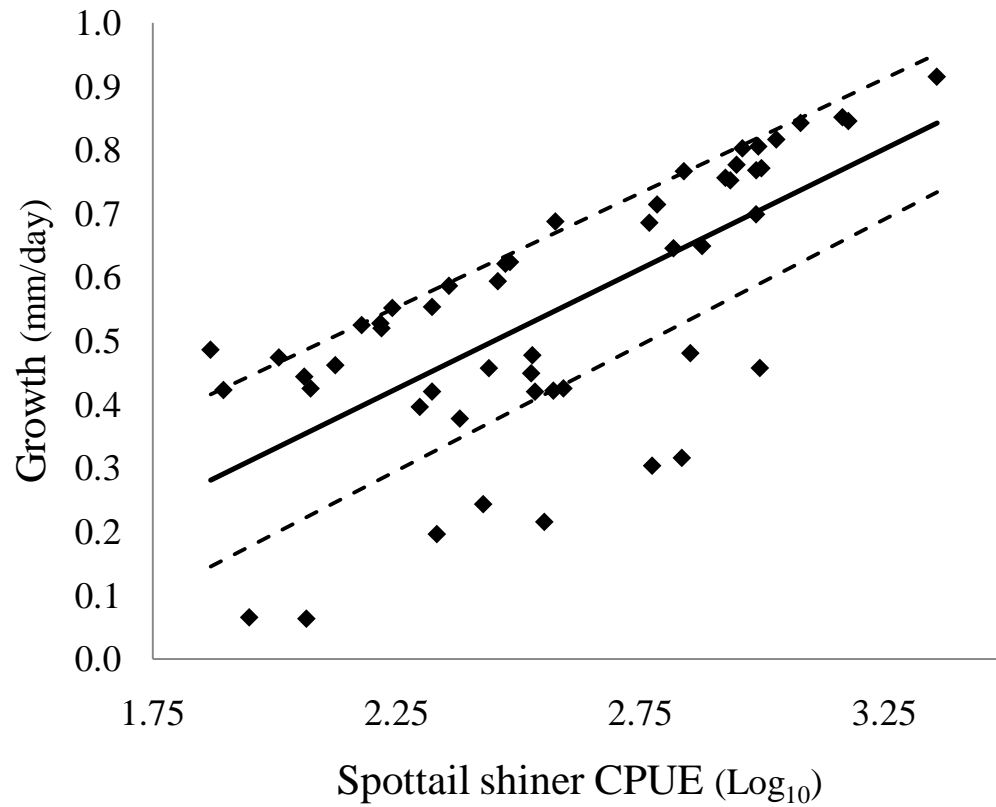


Figure 7. Model predictions of growth (mm/day) of yellow perch age < 1 (Y-axis) as a function of spottail shiner CPUE (Log₁₀) (X-axis), with best fit line and 95% confidence intervals (dashed lines).

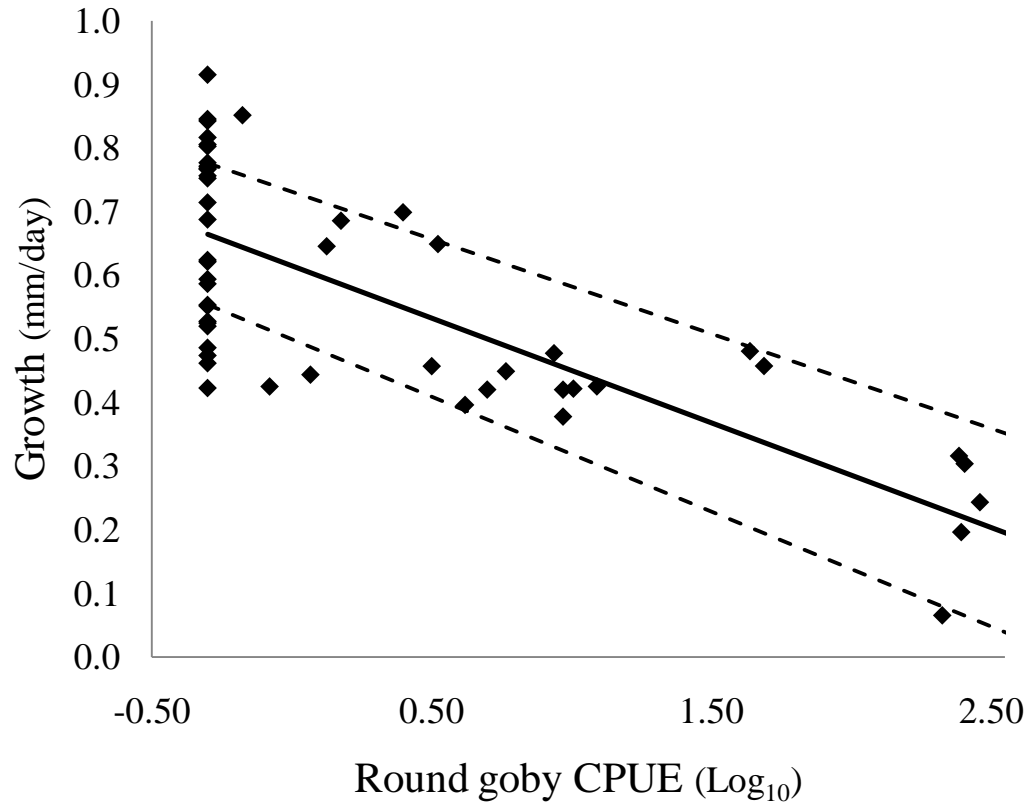


Figure 8. Model predictions of growth (mm/day) of yellow perch age < 1 (Y-axis) as a function of round goby CPUE (Log₁₀) (X-axis), with best fit line and 95% confidence intervals (dashed lines). Round goby did not appear in trawl catches from 1984 - 1997; thus, points that have a round goby CPUE of 0 represent years of predicted yellow perch growth without round gobies.

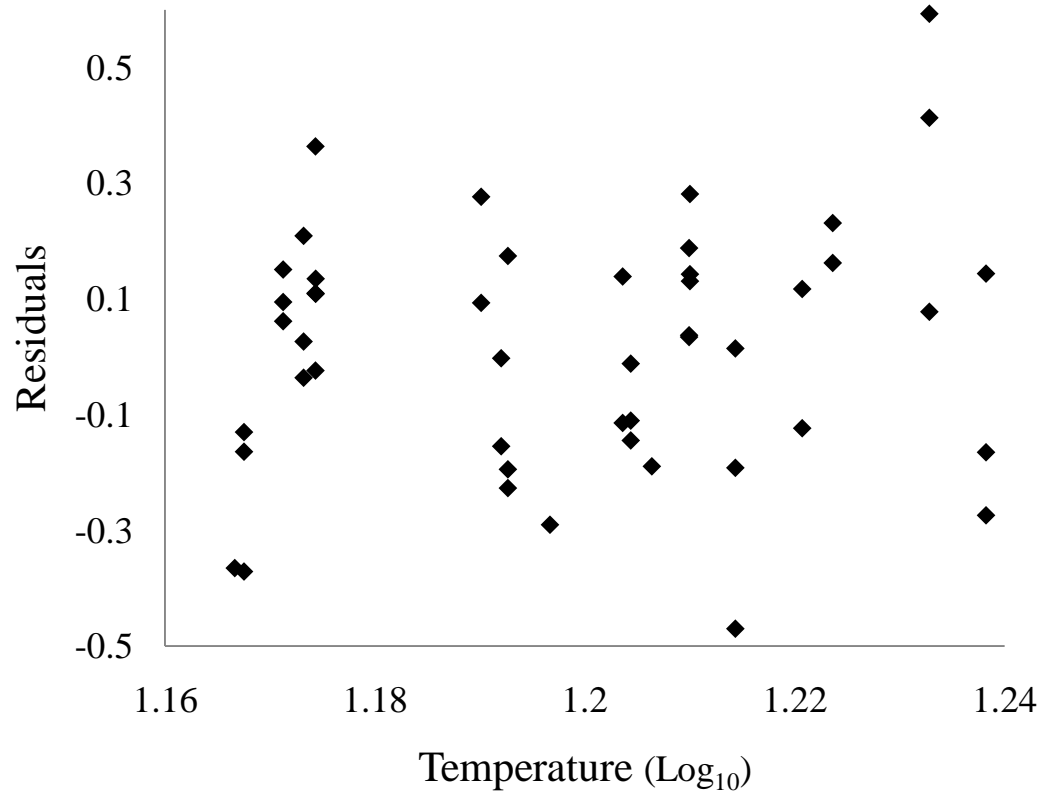


Figure 9. Model residuals (Y-axis) as a function of temperature (Log₁₀) May - Oct. (X-axis).

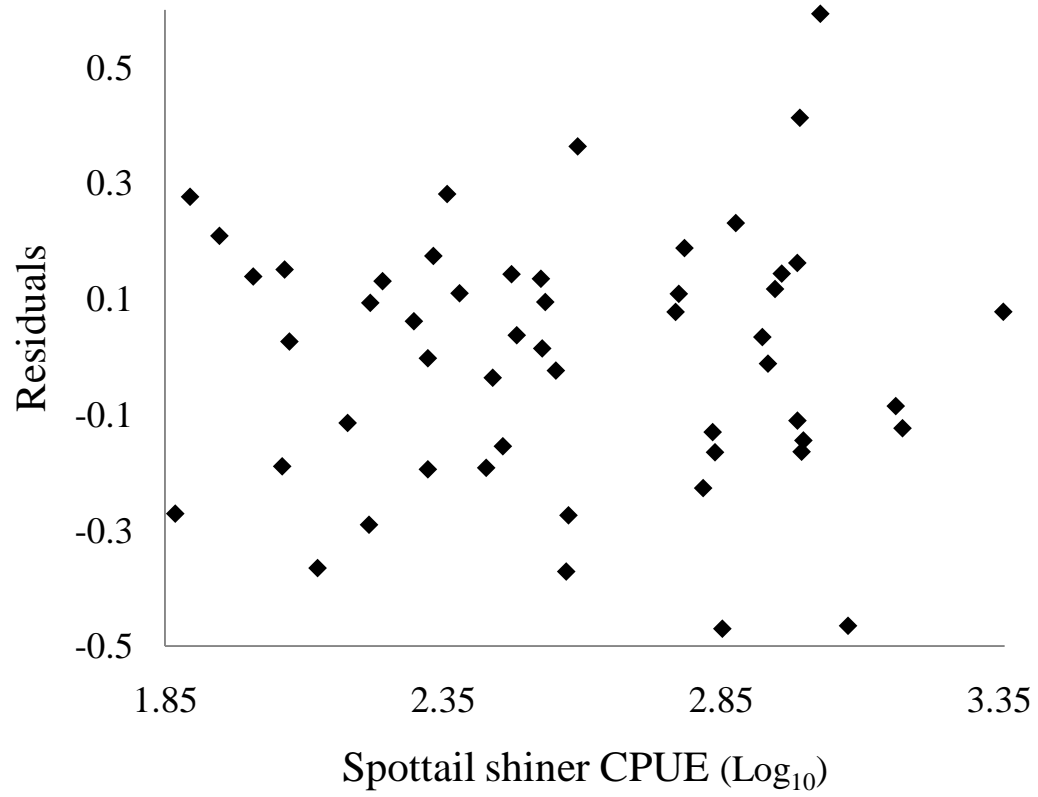


Figure 10. Model residuals (Y-axis) as a function of spottail shiner CPUE (Log₁₀) (X-axis).

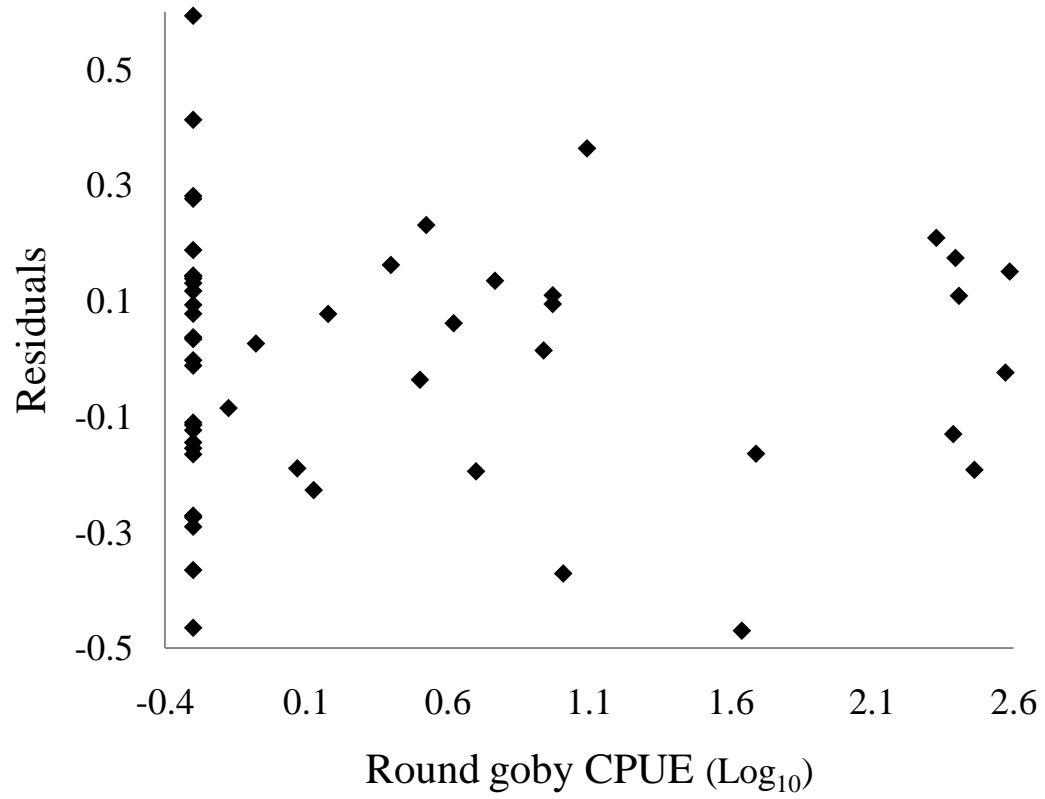


Figure 11. Model residuals (Y-axis) as a function of round goby CPUE (Log₁₀) (X-axis).

Table 1. Parameter estimates, AIC, and probabilities of alternative one parameter models of YOY yellow perch growth rates (mm/day) based on fish collected in August in the Indiana waters of Lake Michigan, 1984 - 2007. See text for abbreviations.

Model	β	SE	F	df	P	AIC
T	5.86	1.51	15.0	47	< 0.001	14.9
SPS	0.40	0.09	19.9	47	< 0.001	15.2
ROG	-0.16	0.04	20.2	47	< 0.001	15.4
YEP	-0.28	0.08	11.7	47	< 0.001	22.3
ALE	-0.27	0.09	9.0	47	< 0.001	24.4
SD	0.06	0.07	0.7	43	0.400	29.8
YOY	-0.11	0.07	2.4	47	0.130	30.1

Table 2. Model selection results describing the influences of biotic and abiotic variables on YOY yellow perch growth rate (mm/day) measured in August in the Indiana waters of Lake Michigan, 1984 - 2007. See text for abbreviations.

Model	β	SE	F	df	P	AIC
<i>Growth</i> = T + SPS						
T	2.843	1.69	2.85	46	0.098	9.7
SPS	0.313	0.10	9.20	46	0.004	
<i>Growth</i> = T + SPS + ROG						
T	1.266	1.68	0.57	45	0.455	1.5
SPS	0.299	0.09	10.20	45	0.003	
ROG	-0.134	0.04	12.12	45	0.001	
<i>Growth</i> = T + SPS + ROG + YEP						
T	1.169	1.68	0.49	44	0.489	5.5
SPS	0.238	0.11	5.04	44	0.030	
ROG	-0.148	0.04	12.69	44	0.001	
YEP	-0.090	0.07	1.68	44	0.202	
<i>Growth</i> = T + SPS + ROG + ALE						
T	1.029	1.69	0.37	44	0.547	3.1
SPS	0.323	0.10	11.24	44	0.002	
ROG	-0.103	0.05	4.55	44	0.039	
ALE	-0.107	0.10	1.08	44	0.303	

CHAPTER 2: Migration and spatial distribution of YOY yellow perch in the Indiana waters of Lake Michigan

Abstract - Age-0 yellow perch were collected from Lake Michigan to identify details of early life history including timing of migration to pelagic waters, timing of return to nearshore waters, and spatial distribution following return to nearshore waters. Tucker trawl catches (larval fish) during 2009 and bottom trawl catches (demersal YOY) during 1983 - 2009 were used in the analysis. Yellow perch larvae were collected from June 1 to June 24, with the majority collected on June 1 (72%) in 2009. Return date for demersal YOY yellow perch ranged from July 8 to August 16, with a mean return date of July 25. Analysis of spatial distribution reflected a relatively homogenous distribution of YOY yellow perch in Indiana nearshore waters. Identifying details of yellow perch early life history provides baseline knowledge to increase efficiency of future YOY sampling that may provide some indication of the mechanisms controlling year class strength and ultimately, recruitment.

INTRODUCTION

Yellow perch, *Perca flavescens*, has been an extensively harvested commercial fish, and continues to be a sought after sport fish and important member of the nearshore Lake Michigan fish community (Marsden and Robillard 2004). Annual commercial harvest was greater than 550 metric tons from 1985 - 1994 (Brofca and Marsden 1993) with yellow perch historically accounting for as much as 85% of the annual sport catch (Great Lakes Fishery Commission 1995). Yellow perch abundance in Lake Michigan peaked in the mid- 1980's, declined through the 1990's, and has remained at a reduced level since (Clapp and Dettmers 2004; Marsden and Robillard 2004; Makauskas and Clapp 2008). The low population abundance caused fisheries managers to tighten recreational bag limits, and by 1997, close all commercial fisheries except in Green Bay (Clapp and Dettmers 2004; Marsden and Robillard 2004). Most recently, there has been a collaborative effort lake-wide to identify factors causing yellow perch recruitment failure (Clapp and Dettmers 2004), with a specific focus on early life history (Robillard and Marsden 2001). Since year class strength may be determined by early life history stages (Clady 1976; Anderson et al. 1998), identifying the details of yellow perch spawning, hatch, pelagic drift, return to littoral waters and the related ontogenetic diet shifts is of paramount importance for sound management.

Yellow perch in Lake Michigan spawn from May to June when water temperatures range from 9 to 12°C at depths of 5 to 10 m (Dorr 1982; Perrone et al. 1983). Egg skeins are typically laid on rock cobble substrates that are found along the western shore of Lake Michigan in Illinois and Wisconsin waters (Peronne et al. 1983; Robillard and Marsden 2001). Eggs hatch about 10-12 days following deposition and

yolk-sac larvae begin drifting with the currents, remaining in the pelagic zone for 1 to 2 months before returning to nearshore waters (Scott and Crossman 1973; Wang and Eckmann 1994). During pelagic drift, larval yellow perch feed mainly on zooplankton (Noble 1975), while later in the summer, larger young-of-the-year (YOY) fish adopt a demersal lifestyle in nearshore waters feeding on benthic invertebrates (Mayer et al. 2000; Dettmers et al. 2005). Similar spatial and feeding transitions have been described for yellow perch populations in small lakes but the specific processes and mechanisms are not well understood for large systems like Lake Michigan (Whiteside et al. 1985; Wang and Eckmann 1994; Urho 1996; Dettmers et al. 2005). Due to offshore drift, larval fish can be transported far from their natal location and only transition back to littoral waters when currents, swimming ability, and gape width allow (Robillard and Marsden 2001; Clapp and Dettmers 2004; Dettmers et al. 2005; Graeb et al. 2006; Beletsky et al. 2007). Beletsky et al. (2004) modeled this yellow perch drift and found that despite spawning locations that appear to be limited to the western shore of Lake Michigan, YOY yellow perch were widely dispersed in the southern basin. These findings were supported genetically (Miller 2003) and gave further credence to the drift-dispersal hypothesis. By characterizing the early life history of yellow perch in the Indiana portion, we may more fully identify spawning activity, recruitment limitations, dispersal patterns, and habitat use in the entire southern Lake Michigan basin, facilitating yellow perch management (Urho 1996; Dettmers et al. 2005). Included in this understanding would be identifying a more accurate timeline outlining the yellow perch ontogenetic shift in habitat use from the offshore pelagic-drift stage to the nearshore free-swimming stage.

Therefore, our objectives for yellow perch in the Indiana waters of Lake Michigan were to: 1) determine time of larval transition from nearshore hatch sites to pelagic waters, 2) determine time of return of free-swimming, demersal YOY back to nearshore waters, 3) determine whether demersal YOY abundance in catch-per-unit-effort (CPUE) differs spatially in the Indiana waters, and 4) determine whether YOY size measured as total length (mm) differed by sampling unit and zone in the Indiana waters of southern Lake Michigan.

METHODS

Field sampling was conducted in the Indiana waters of southern Lake Michigan. Sample sites were accessed using Indiana, Burns, and Michigan City harbors. Indiana Harbor is located between Hammond and Gary, Indiana. Burns Harbor is located in Portage, Indiana. Michigan City Harbor is located in Michigan City, Indiana.

Offshore migration of yellow perch larvae

Three sampling zones in the Indiana waters were established for sampling larval yellow perch: six km east and west of Michigan City Harbor (zone M), Burns Harbor (zone B), and Indiana Harbor (Zone I) (Figure 1). Each zone was divided into 12 possible sampling units (Hansen et al. 2007) of 1 km wide. At the beginning of each sampling period, a sampling unit was chosen at random from one or more of the three zones with samples taken during the day at three depth contours, 2 - 4 m, 6 - 8 m, and 10 - 12 m. Thus, for any given sampling period, up to nine samples were collected.

Sampling was initiated on June 1 and continued until July 22, 2009. On June 1 samples were only taken from Michigan City Harbor. Beginning June 5 samples were

taken at each harbor twice weekly. After June 18, sampling of Indiana Harbor was discontinued and effort at Burns and Michigan City harbors was reduced to weekly from June 24 – July 22. No samples were taken the first week of July while equipment was down for repair. Sampling effort was dictated by our determination of peak spawn in Indiana waters (i.e., May and June; Walters 2010) based on brood stock stage of maturity (Marsden and Robillard 2004) and the subsequent expected timeline of development as described for yellow perch in other systems (Scott and Crossman 1973; Wang and Eckmann 1994).

Larval sampling consisted of towing a 0.5 m x 0.7 m framed Tucker trawl that fished a 0.25 m² opening with a 300 micron conical ichthyoplankton net behind the boat and outside the wake. The trawl was towed through the water column obliquely from bottom to top made possible by hand winching over the 10 min trawl duration, covering a distance of approximately 625 m (based on the on-board GPS unit). Samples were preserved with 40% ethanol in the field. In the lab larval fish were identified and enumerated to the lowest possible taxonomic level using keys by Lippson (1976) and Auer (1982) with the aid of a dissecting microscope, high powered microscope, and Paxcam Image Capturing system (Villa Park, IL).

The volume of water filtered in each collection was determined using the distance traveled and trawl frame size. Larval density for each tow was determined by number of fish collected per m³ of water filtered.

Temporal onshore migration of post-larval yellow perch

Bottom trawl fish data collected from long-term monitoring were analyzed to determine when age-0 yellow perch transition to a free swimming nearshore demersal

stage. Sampling was conducted from 1983 - 2009 at three sites in the Indiana waters of southern Lake Michigan (Figure 2). Sites M and K are located two km east and west of Michigan City Harbor, respectively, and were sampled from 1983 - 2009, while site G is located six km northwest of Burns Harbor and was sampled from 1989 - 2009 (Figure 2). Substrate at the three sites is predominantly sand with undulating clay ridges at site K (Shroyer and McComish 1998; Lauer et al. 2004).

Fish were sampled with a semi-balloon otter trawl that had a 4.9 m head rope, 5.8 m footrope, 38 mm stretched mesh nylon body, and 32 mm stretched mesh cod end with a 13 mm nylon liner. It was fished at night bi-monthly from June through August along the 5 m depth contour at an average tow speed of 5.5 - 6.0 km/h a distance of approximately 1 km per tow. A sample consisted of six 10 min tows for a total trawling effort of one hour per night. Fish were immediately stored on ice and processed dockside (identified and enumerated) within 12 hours of capture.

Daily water temperature (May - June) was obtained from Saint Joseph Water Filtration Plant, Saint Joseph, Michigan. Regression analysis was used to test for a relationship between the dependant variable of return date and independent variables of year and water temperature. Return dates for each site from the years 1983 - 2009 were converted to Julian day and a mean and standard deviation was calculated to estimate mean annual date of onshore migration of post-larval yellow perch.

Spatial onshore distribution of demersal age-0 fish

During nighttime hours of July 30-31, 2009, yellow perch trawl samples were randomly collected from the Michigan City Harbor and Burns Harbor zones (Figure 1) to determine whether demersal age-0 yellow perch abundance varied along the Indiana

shoreline. Sampling units were numbered in 1 km increments from east to west, with units 1-12 in zone M and units 13-24 in zone B. Six sampling units were chosen at random from each of the two zones with samples taken at the 5 m depth contour from 6 km east of Michigan City Harbor mouth to 6 km west of Burns Harbor mouth. Trawl collections followed the same procedures as the long-term monitoring. Fish were placed on ice and total lengths (mm) were measured in the lab.

A two sample *t*-test was used to determine whether abundance measured in catch-per-unit-effort (CPUE) (fish/hr) of YOY yellow perch collected at zone M differed from zone B. Abundance data were \log_{10} transformed before analysis to meet the normality assumption. A second two sample *t*-test was used to determine whether mean total length (mm) of YOY yellow perch collected at zone M differed from those collected at zone B. Analysis of variance was used to determine whether differences in mean total length (mm) existed by sample unit in the Indiana waters of southern Lake Michigan.

RESULTS

Offshore migration of yellow perch larvae

A total of 18 yellow perch larvae was collected in the Indiana waters of Lake Michigan. Yellow perch larvae appeared in 6 of 74 samples on 3 of 13 sample days. Catch densities (larvae/m³) of yellow perch larvae ranged from 0.000 to 0.065 larvae/m³ (Tables 1 - 5). The majority of yellow perch larvae (72%) were collected from site M on June 1 (Table 1). Yellow perch larvae were collected at all sampled depth contours from 2 m to 12 m with the majority collected at depths ≥ 10 m (Table 1; Table 3; Table 5).

Eighty-three percent of yellow perch larvae were collected from zone M (Table 1; Table 5).

Temporal onshore migration of post-larval yellow perch

First date of collection of demersal age-0 yellow perch ranged from July 8 to August 16 over the period 1983 - 2009 (Figure 3). There was no relationship between return date and water temperature ($F = 901$, $N = 24$, $P = 0.35$) or return date and year ($F = 730$, $N = 27$, $P = 0.40$). The mean (SD) date of return was July 25 (10) days.

Spatial onshore distribution of demersal age-0 fish

A total of 1404 YOY yellow perch was caught on July 30-31 from 12 sample units in the Indiana waters of southern Lake Michigan. Yellow perch CPUE ranged from 42 to 1800 fish/hr (Figure 4) with a mean (SE) CPUE of 146 (281) fish/hr ($N = 6$) in zone M and 762 (48) fish/hr ($N = 6$) in zone B (Figure 5). Abundance of YOY yellow perch in zone M did not differ from zone B ($t = -1.17$, $df = 10$, $P = 0.26$).

Mean (SE) total length (mm) of yellow perch ranged from 44.3 (1.0) mm ($N = 13$) at unit 8 to 48.9 (0.3) mm ($N = 243$) at unit 19 (Figure 6; Figure 7), with a mean (SE) of 46.7 (0.8) mm ($N = 928$) for all sampling units combined. Mean (SE) was 46.4 (0.3) mm ($N = 146$) in zone M and 47.4 (0.2) mm ($N = 762$) in zone B (Figure 5). Mean total lengths (mm) of YOY yellow perch caught in zone B were larger than those caught in zone M ($t = -2.86$, $df = 214$, $P < 0.01$). Mean total lengths (mm) of YOY yellow perch differed by unit ($F = -5.69$, $df = 11$, $P < 0.01$).

DISCUSSION

Offshore migration of yellow perch larvae

Relatively few yellow perch larvae were collected in the Indiana waters of Lake Michigan in 2009. These abundances were lower in number and density than found in southwestern (Dettmers et al. 2001) and southeastern (Perrone et al. 1983) Lake Michigan. Yellow perch larvae densities were generally considered scarce by Perrone et al. (1983).

The low abundance of yellow perch larvae in 2009 could be the result of several factors. Because the majority of yellow perch larvae were caught on the first sampling day with decreases thereafter, this implies sampling might have begun well after yellow perch larvae were present in the water column. However, support for this late sampling hypothesis may be problematic for four reasons. First, Dettmers et al. (2005) sampled a nearby location during 2000 - 2002 and failed to find any yellow perch larvae prior to June 1. Second, the low numbers of fish actually caught ($N = 18$) preclude meaningful statistical treatment. Third, the peak spawning period in these waters during 2009 appeared to occur on May 24 (Walters 2010). Assuming 10 days are required for the eggs to hatch and enter the water column (Scott and Crossman 1973), it is unlikely large numbers of larvae were moving offshore prior to our initial sampling. Lastly, larval sampling was only during daylight hours. Yellow perch larvae exhibit diel distribution in the water column, with nighttime catches typically exceeding daytime catches (Perrone et al. 1983). Our sampling did consistently find non-percid larvae in great abundances (personal observation), suggesting our larval trawl deployment methodology was sound. Despite these limitations on design or timing of our sampling, our best conclusion for the low abundance of yellow perch larvae in this portion of the lake is that they were simply not present.

Reasons for the limitation of larval yellow perch in the Indiana waters of Lake Michigan are likely abiotic in nature. The substrate in the Indiana waters is relatively homogenous, comprised of clay and sand lacking rocky substrates preferred by yellow perch for spawning (Shroyer and McComish 1998; Robillard and Marsden 2001; Lauer et al. 2004). Because of this lack of spawning habitat, the Indiana waters of Lake Michigan are believed to contribute little to yearly yellow perch production (Dettmers et al. 2005; Janssen et al. 2005; Wilberg et al. 2008). The actual densities of yellow perch larvae collected in Indiana waters could be the result of successful spawning on the limited rocky habitats available in Indiana waters, such as break walls or rip-rap surrounding harbors. Alternatively, currents may carry newly hatched yellow perch larvae into Indiana from Illinois where there is higher quality and more abundant spawning substrates (Robillard and Marsden 2001; Beletsky et al. 2007). In either case, our findings support previous hypotheses (Shroyer and McComish 1998; Robillard and Marsden 2001; Lauer et al. 2004; Dettmers et al. 2005; Janssen et al. 2005; Wilberg et al. 2008) that the Indiana waters contribute little to yearly spawning events for yellow perch in Lake Michigan.

Temporal onshore migration of post-larval yellow perch

Our analysis of bi-monthly trawl surveys from 1983 - 2009 indicated that YOY yellow perch would initially return to nearshore waters on July 25 ± 10 days. This calculated return date was expected, given the known spawning period from mid-May to June in Lake Michigan (Perrone et al. 1983; Walters 2010) and the understanding that the pelagic life stage of yellow perch has been suggested to last up to two months (Wang and Eckmann 1994; Dettmers et al. 2008). Knowing the mean timing for the transition from

pelagic life stage back to demersal life stage in Indiana's nearshore waters equips lake managers with another detail of yellow perch early life history that can facilitate more informed study design, reducing time and money investment when sampling YOY. Further, understanding when fish return to Indiana aides future probative attempts at identifying the relationship between early life history stages and the biotic variables influencing recruitment success (i.e. diet shift from yolk sac to zooplankton and zooplankton availability, Dettmers 2003).

Spatial onshore distribution of demersal age-0 fish

Our single night sampling results from 12 locations suggested abundance did not differ between study zones over a 45 km length of shoreline. The random distribution of demersal YOY yellow perch may be a reflection of relatively homogenous physical structure (i.e., substrate; Figure 2) not promoting distinct habitat patches that influence selectivity and use patterns (Kilgore et al. 1989; Weaver et al. 1997). Further, modeling results demonstrated that YOY yellow perch settlement can occur anywhere in the southern basin of Lake Michigan and is dependent on currents (Beletsky et al. 2007). However, our failure to find differences in abundance by zone could be due to small sample size and environmental stochasticity, rather than identifying meaningful support for the null hypothesis (type II error; Zarr 1999).

Range and mean of the total lengths of the YOY yellow perch sampled on July 30-31 are similar to other estimates (Mills and Forney 1981; Compton and Kerfoot 2004; Graeb et al. 2006) for this time of year and life stage. Our analysis demonstrated statistically significant differences in mean total length by both harbor zone and site, but these differences may not merit biological importance. Length frequency analysis of bi-

monthly yellow perch trawl catches in 2009 demonstrated a daily growth rate of 0.44 mm for age-0 fish (Figure 8). Considering the small mean difference in age-0 fish size between the two zones (1.4 mm) coupled with the two-week period of known spawning in 2009 (Walters et al. 2010), size differences could reflect multiple spawning dates and locations (Prout et al. 1990; Robillard and Marsden 2001; Čech et al. 2007), varying currents moving the pelagic larvae (Beletsky et al. 2007), patchy distribution of prey (Dettmers et al. 2003), or thermal regimes (Čech et al. 2007).

Management Implications

The early life stages of yellow perch have been identified as a key factor in limiting yellow perch recruitment in Lake Michigan (Houde 1987; Heyer et al. 2001; Clapp and Dettmers 2004). In spite of this, the majority of research on yellow perch has excluded the age-0 cohort from study. Our identification of minimal spawning activity in the Indiana waters of Lake Michigan and the onshore random movement of pelagic free swimming age-0 fish suggests the Indiana waters may act as a sink in the source-sink dynamics of yellow perch recruitment in Lake Michigan (Beletsky et al. 2007; Wilberg et al. 2008). A precise timeline for the early life history stages of YOY yellow perch can clearly aide development of study designs for analysis, habitat protection and enhancement (Robillard and Marsden 2001), understanding predator-prey interactions including zooplankton and other (larger) fish (Brandt et al. 1987; Sanderson et al. 1999; Dettmers et al. 2003), among other items.

Our analysis of the spatial distribution of demersal YOY yellow perch provides a preliminary assessment that can be built upon and with future research and analysis make a contribution to understanding YOY spatial distribution lake wide.

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Figure 1. Map of three sample zones (M, B, and I) in the Indiana waters of southern Lake Michigan.

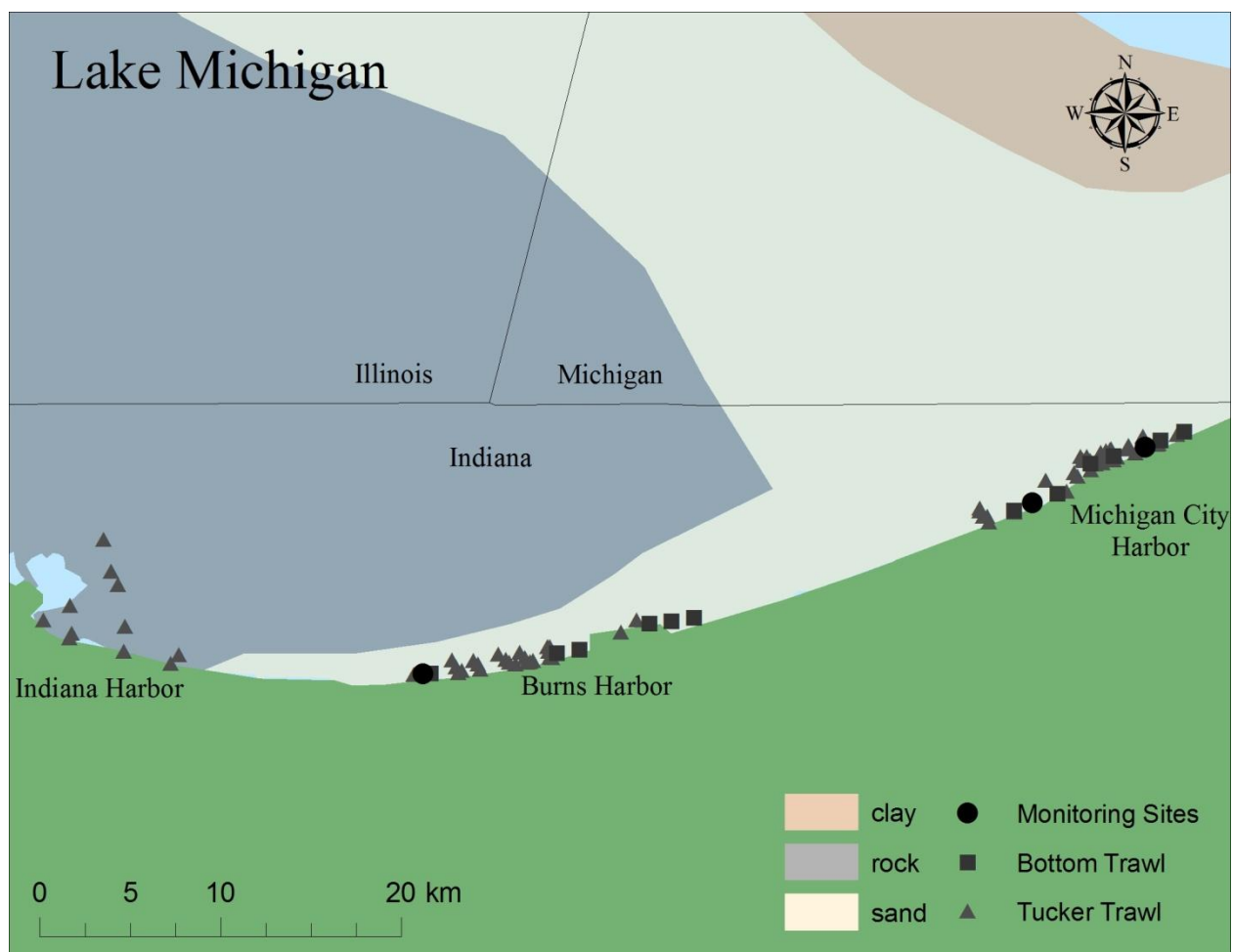


Figure 2. Map of all study sites in the Indiana waters of southern Lake Michigan.

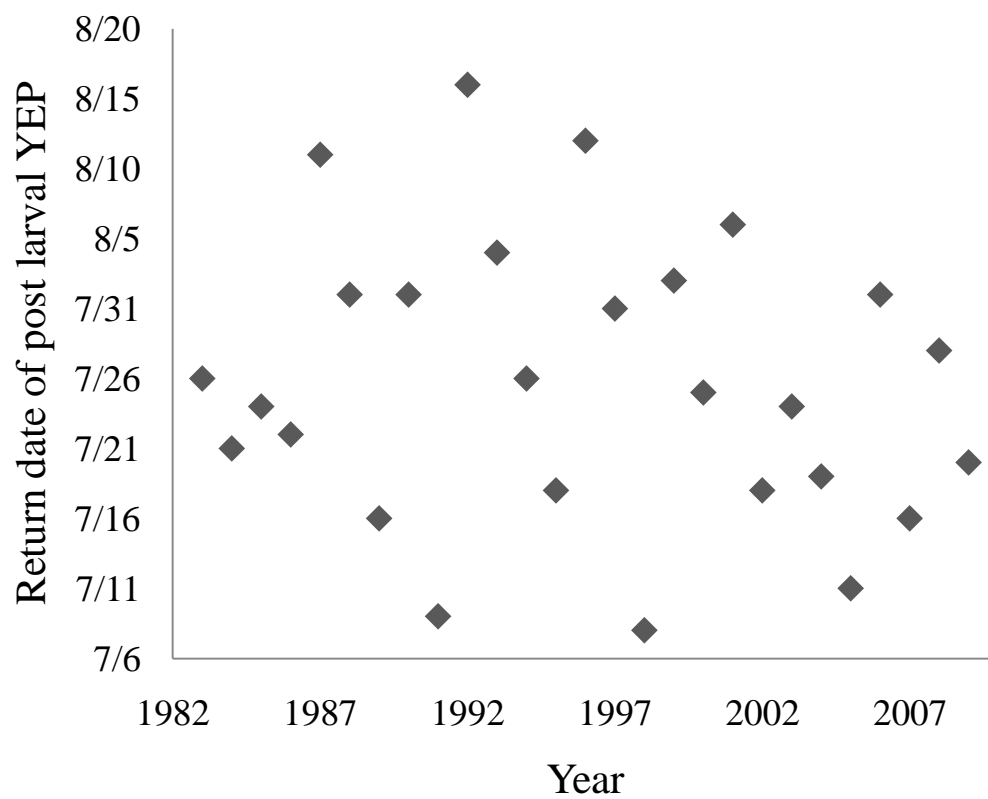


Figure 3. Return dates (y-axis) from the years 1983 - 2009 (x-axis), of post-larval yellow perch to nearshore waters for sites M, K, and G in southern Lake Michigan.

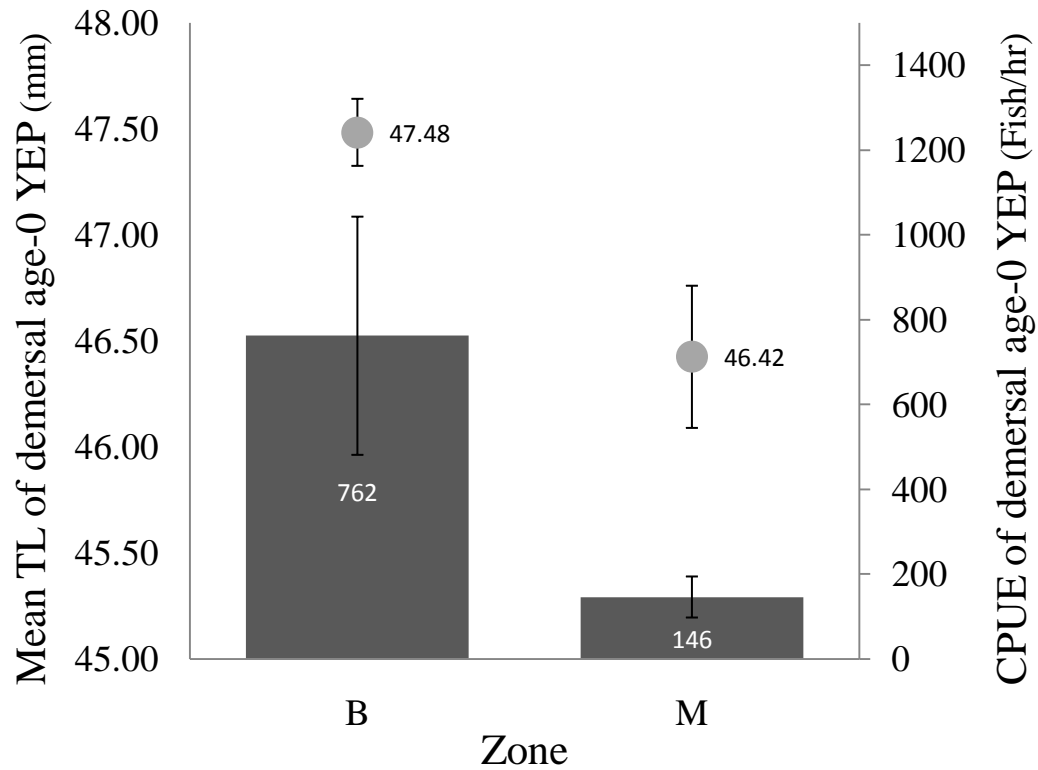


Figure 4. Mean total length (mm) with error bars (standard error) plotted with points (primary y-axis), CPUE (fish/hr) with error bars (standard error) plotted with bars (secondary y-axis) by study zone (x-axis) of age-0 demersal yellow perch in the Indiana waters of southern Lake Michigan in 2009.

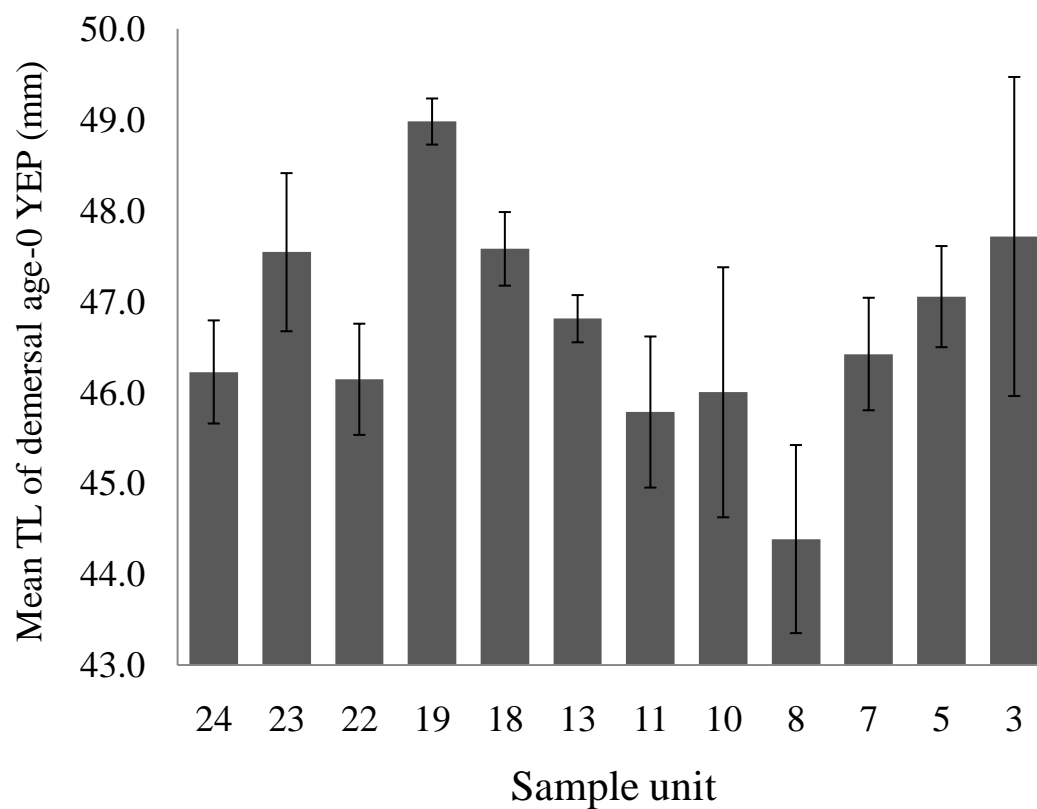


Figure 5. Mean total length (mm) with error bars (standard error) (y-axis) by sample unit (x-axis) of age-0 demersal yellow perch in the Indiana waters of southern Lake Michigan in 2009.

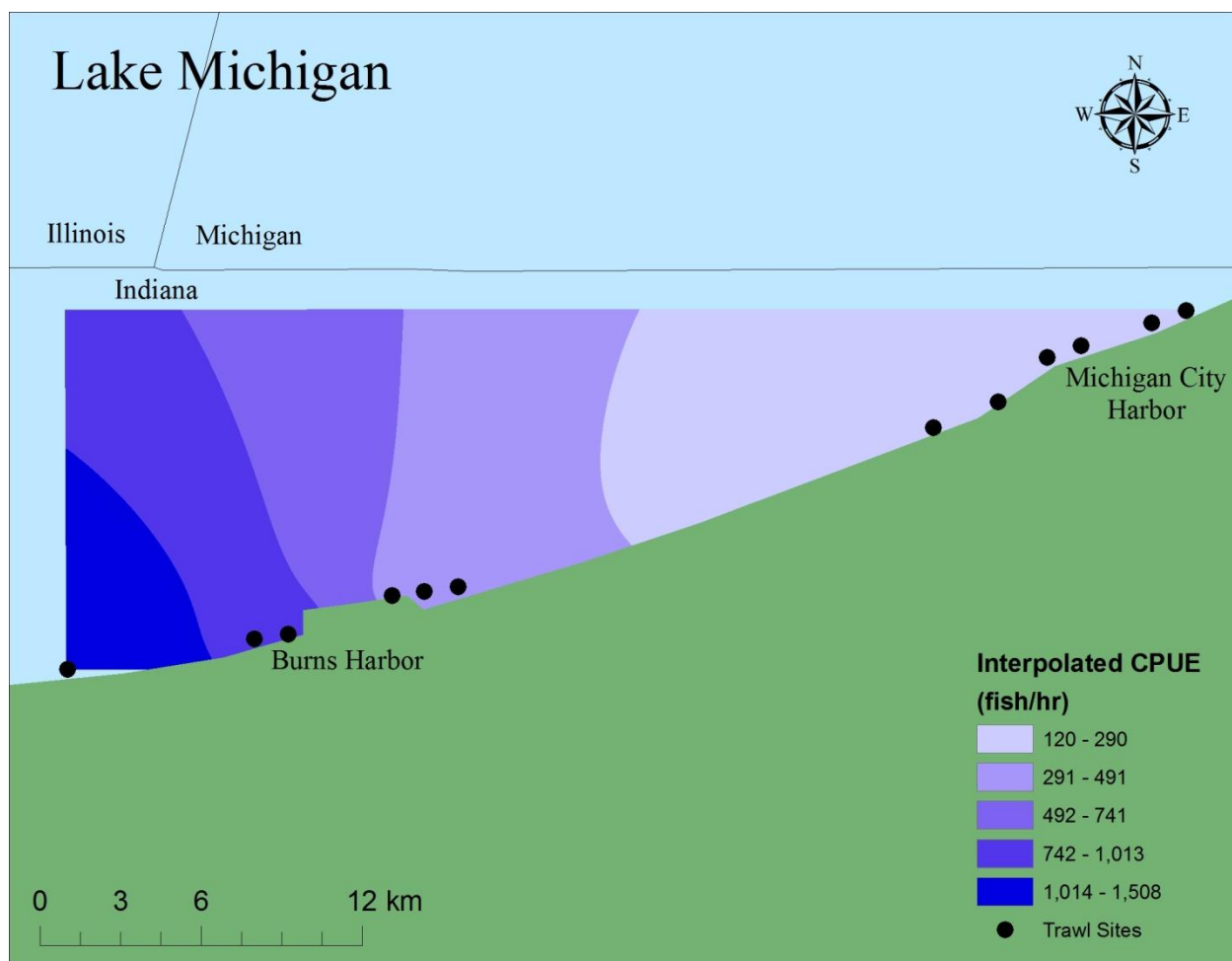


Figure 6. Interpolated plot of abundance measured in CPUE (fish/hr) of age-0 demersal yellow perch in the Indiana waters of southern Lake Michigan in 2009. Interpolated by kriging method in ArcGIS using CPUE (fish/hr) collected for each site.

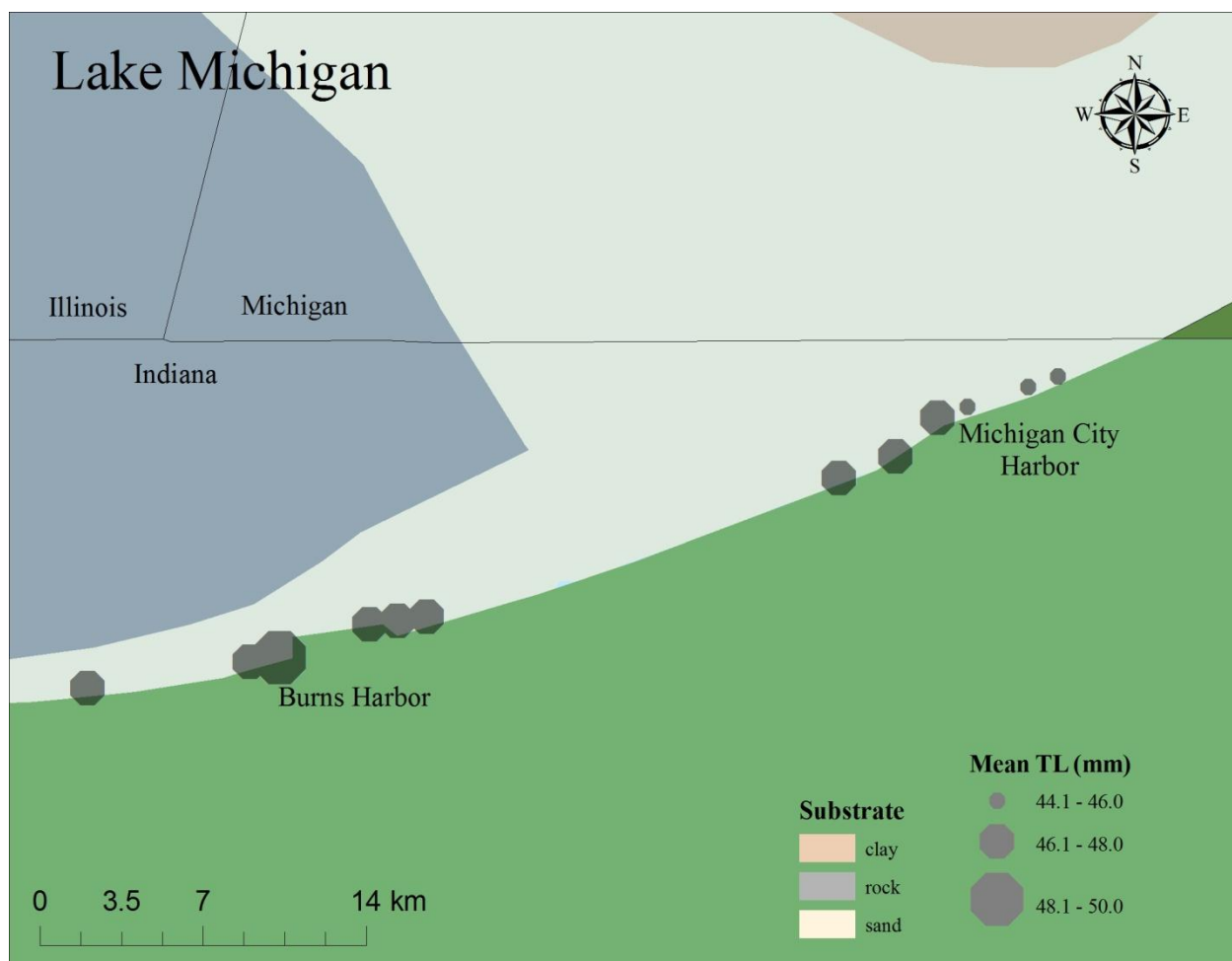


Figure 7. Sample units with mean total length (mm) circles demonstrating size of age-0 demersal yellow perch in the Indiana waters of southern Lake Michigan in 2009.

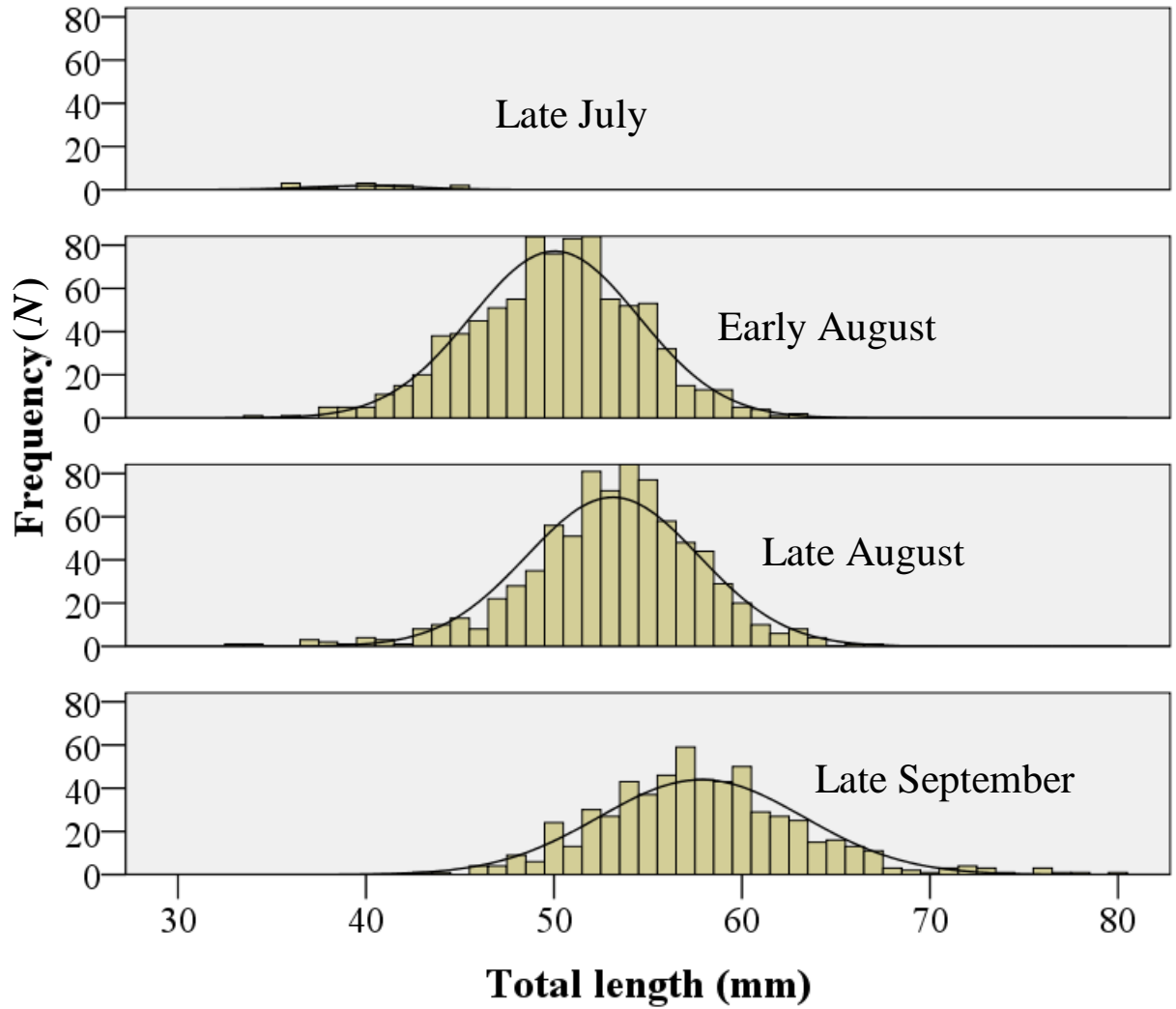


Figure 8. Length frequency distributions for post-larval yellow perch collected in monitoring trawls at sites M, K, and G in the Indiana waters of southern Lake Michigan in 2009.

Table 1. Count and density (N/m^3) of yellow perch larvae collected with tucker trawl in southern Lake Michigan on June 1, 2009.

Date	Zone	Depth	N	Density (N/m^3)
6/1	M	12	9	0.065
6/1	M	10	4	0.032
6/1	M	8	0	0.000
6/1	M	6	0	0.000
6/1	M	4	0	0.000

Table 2. Count and density (N/m^3) of yellow perch larvae collected at the 10 to 12 m depth contour with tucker trawl from sites in zones M, B, and I in southern Lake Michigan from June 5 to June 18, 2009.

Date	Zone	N	Density (N/m^3)
6/5	B	0	0
6/5	I	0	0
6/5	M	0	0
6/9	B	0	0
6/9	I	0	0
6/10	M	0	0
6/12	B	0	0
6/12	I	0	0
6/12	M	0	0
6/16	I	0	0
6/16	B	0	0
6/17	M	0	0
6/18	B	0	0
6/18	I	0	0
6/18	M	0	0

Table 3. Count and density (N/m^3) of yellow perch larvae collected at the 6 to 8 m depth contour with tucker trawl from sites in zones M, B, and I in southern Lake Michigan from June 5 to June 18, 2009.

Date	Zone	N	Density (N/m^3)
6/5	B	0	0.000
6/5	I	0	0.000
6/5	M	0	0.000
6/9	B	0	0.000
6/9	I	0	0.000
6/10	M	0	0.000
6/12	B	1	0.009
6/12	I	0	0.000
6/12	M	0	0.000
6/16	B	0	0.000
6/16	I	0	0.000
6/17	M	0	0.000
6/18	B	0	0.000
6/18	I	0	0.000
6/18	M	0	0.000

Table 4. Count and density (N/m^3) of yellow perch larvae collected at the 2 to 4 m depth contour with tucker trawl from sites in zones M, B, and I in southern Lake Michigan from June 5 to June 18, 2009.

Date	Zone	N	Density (N/m^3)
6/5	B	0	0
6/5	I	0	0
6/5	M	0	0
6/9	B	0	0
6/9	I	0	0
6/10	M	0	0
6/12	B	0	0
6/12	M	0	0
6/16	B	0	0
6/16	I	0	0
6/17	M	0	0
6/18	B	0	0
6/18	I	0	0
6/18	M	0	0
6/12	I	0	0

Table 5. Count and density (N/m^3) of yellow perch larvae collected with tucker trawl from sites in zones M and B in southern Lake Michigan from June 24 to July 22, 2009.

Date	Zone	Depth	N	Density (N/m^3)
6/24	B	10 to 12	2	0.010
6/24	B	6 to 8	0	0.000
6/24	B	2 to 4	0	0.000
6/24	M	10 to 12	0	0.000
6/24	M	6 to 8	1	0.005
6/24	M	2 to 4	1	0.005
7/9	M	10 to 12	0	0.000
7/9	M	6 to 8	0	0.000
7/9	M	2 to 4	0	0.000
7/9	B	10 to 12	0	0.000
7/9	B	6 to 8	0	0.000
7/9	B	2 to 4	0	0.000
7/13	M	10 to 12	0	0.000
7/13	M	6 to 8	0	0.000
7/13	M	2 to 4	0	0.000
7/13	B	10 to 12	0	0.000
7/13	B	6 to 8	0	0.000
7/13	B	2 to 4	0	0.000
7/21	B	6 to 8	0	0.000
7/22	M	6 to 8	0	0.000